SIDEROPHILE ELEMENT EVIDENCE INDICATES THAT APOLLO 14 HIGH-AL MARE BASALTS ARE NOT IMPACT MELTS

PAUL H. WARREN, GREGORY W. KALLEMEYN and FRANK T. KYTE

Institute of Geophysics and Planetary Physics, UCLA, Los Angeles, CA 90095-1567, USA

The high-Al mare basalts from Apollo 14 include most of the oldest individual mare samples known, with Rb-Sr ages in several cases between 4.1 and 4.3 Ga [1,2]. However, the Nd isotopic systematics for the same samples are generally disturbed, even though under most circumstances Nd isotopes probably tend to be more resistant to disturbance than Sr isotopes. At last year's LPS Conference it was suggested by Snyder and Taylor [3] that the linear arrays on the Rb-Sr diagrams are merely "errorchrons" caused by mixing of older highland plagioclase with essentially mare-composition impact melt. Besides possibly explaining the isotopic evidence, this model provides a mechanism to engender the unusually high Al content characteristic of this suite of mare basalts.

To test the impact melt hypothesis, we have employed RNAA to determine siderophile elements in two Apollo 14 mare basalt breccia clasts, and we note that data have been published previously for an additional three Apollo 14 mare basalts (Table 1). For reference, the average composition is shown normalized to 3×10^{-4} times CI chondrites. Compositionally pristine lunar rocks generally have concentrations of highly siderophile elements below this level. Lunar rocks contaminated with meteoritic debris, including all known cases of lunar impact melt products (or at least, all known cases of fine-grained lunar impact melt products), have concentrations far above 3×10^{-4} times CI [6]. Among the five samples in Table 1, only 14305,215 contains the refractory siderophile elements (Re, Os and Ir) at levels close to 3×10^{-4} times CI. The other four appear to be very typical mare basalts.

The 14303,215 sample is from a small (15×5 mm), severely brecciated clast in an impact melt breccia. Thin section 14303,227 shows that a minor proportion (roughly 1/5) of the clast's volume consists of surviving clasts (within the clast) of little-brecciated subophitic basalt, with grains typically about 0.5 mm in maximum dimension. Most of the area, however, is a groundmass of cataclastic debris with typical grain size of the order 30 µm. Some areas also show signs of mild post-brecciation annealing. This clast may be far from ideally monomict.

The 14304,113 sample is from the subophitic basalt clast "c" that was described petrographically by Goodrich et al. [7], and dated at 3.95±0.04 Ga based on Rb-Sr, and 3.85±0.04 Ga based on ^{39}Ar-^{40}Ar, by Shih et al. [2]. Even with 14303,215 included, the average concentration for each of the refractory siderophile elements (Re, Os and Ir) is far below 3×10^{-4} times CI — indicating that the samples are "meteorite-free."

The consistent Ge enrichments are curious, but in the absence of comparable enrichments in more refractory siderophile elements such as Re, Os and Ir, they can hardly be taken as evidence for a component of impactor debris. More likely they are a peculiarity that developed in central nearside basalts as an indirect consequence of the region's extraordinary richness in KREEP, as suggested by Dickinson et al. [8].

These basalts feature significantly higher Al contents than nearly all other mare basalt types. However, the magnitude of this disparity has been somewhat exaggerated in the past, because several of the seminal studies of this rock type [e.g., 9,10] involved data obtained using the defocused beam analysis (DBA) technique without correcting for the unequal host-phase density effect [see companion abstract: 11]. Without such correction, application of the DBA technique to mare basalts inevitably leads to erroneously high Al (and low Mg+Fe+Ti) in the results. The siderophile evidence indicates that the moderately high Al contents of these samples are results not of impact-mixing, but rather of a distinctive style of endogenous magmatism. Again, the unusual style may have been indirectly caused by the region's extraordinary richness in KREEP, which (among other effects) might have kept the regional crust warm and thus uncommonly prone to interaction with magmas (and in particular early magmas) ascending from the mantle. Even the unusual tendency for Nd isotopes to be more disturbed than Sr isotopes is conceivably a consequence of the regional KREEP enrichment. It has often been suggested [12], that as URKREEP matured it split into an alkali-rich, REE-poor "K-fraction" and an alkali-poor, REE-rich "REEP-fraction." If so, then these basalts might, through a variety of conceivable scenarios, have tended to undergo disturbance in proximity to the FeO-rich (and thus high-density) "REEP-fraction" and far from the FeO-poor (and thus low-density) "K-fraction."

The true explanation for the Nd disturbances may be quite unrelated to KREEP; and Snyder and Taylor [3] may be correct in regarding the Rb-Sr ages as in some fashion erroneous. But the suggestion that these materials may be impact melt products seems implausible, based on the siderophile evidence.

References: [1] Dasch E. J. et al. (1987) *GCA* **51**, 3241-3254. [2] Shih C.-Y. et al. (1987) *GCA* **51**, 3255-3271. [3] Snyder G. A. & Taylor L. A. (1996) *LPS* **XXVII**, 1233-1234. [4] Morgan J. W. et al. (1975) *GCA* **39**, 261-264. [5] Warren P. H. et al. (1986) *PLPSC* **16**, D319-D330. [6] Haskin L. A. & Warren P. H. (1991) in *Lunar Sourcebook, A User's Guide to the Moon* (G. Heiken et al., eds.), Cambridge Univ. Press, p. 357-474. [7] Goodrich C. A. et al. (1986) *PLPSC* **16**, D305-D318. [8] Dickinson T. et al. (1989) *PLPSC* **19**, 189-198. [9] Grieve R. A. F. et al. (1975) *GCA* **39**, 229-245. [10] Ridley W. I. (1975) *PLSC* **6**, 131-145. [11] Warren P. H. (1997) *LPS* **XXVIII**, this volume. [12] Neal C. R. & Taylor L. A. (1989) *GCA* **53**, 529-541.

Table 1. Bulk-rock concentrations of Fe and trace siderophile elements in Apollo 14 high-Al mare basalts.

		wt%	μg/g	μg/g	ng/g	pg/g	pg/g	pg/g	ng/g	
sample	**brief description**	**Fe**	**Co**	**Ni**	**Ge**	**Re**	**Os**	**Ir**	**Au**	**source**
14053,26	large (250 g) unbrecciated rock	13.2				6.6		17	0.11	[4]
14181,6	little-brecciated clast	12.1	28.7	4	175	<3	11	1.5	0.147	[5]
14303,215	intensely brecciated clast	15.2	41.5	100	1000	12	133	152	2.9	this work
14304,113	little-brecciated clast	13.4	41.2	30	250	<9	<40	6.1	0.042	this work
14321,184,1B	clast, probably little-brecciated				640	5		44	0.30	[4]
	average	13.6	37	45	520	7	60	40	0.7	
	normalized to 3×10^{-4} times CI			14	50	0.6	0.4	0.3	16	
	average excluding 14303,215	12.8	35	17	350	5	11	17	0.15	
	normalized to 3×10^{-4} times CI			5	36	0.5	0.07	0.12	4	